MAT-90-10

Quantitative Evaluation of the Effectiveness of Erosion Control Materials

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Abstract: This study was initiated to develop quantitative methods to assess the effectiveness of temporary erosion control products used in highway construction. A field methodology was developed employing rainfall simulation techniques to measure soil and runoff losses on highway construction slopes prepared to design specifications.

The findings suggest an approach both for the equitable evaluation of the many diverse kinds of erosion control materials/products available and a methodology for the determination of the most appropriate and cost-effective erosion control materials/products to be used that matches the erosion susceptibility of the site.

Comments: Initial results in testing the erosion control effectiveness model. Work in testing additional materials was continued in 1990/1991.

Key Words: universal soil loss equation (U.S.L.E.), erosion control, erosion control blankets, erosion control mulches, rainfall simulation, rainfall simulator

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1/ Background

The Ontario Ministry of Transportation (MTO) has primarily depended on the use of commercial hydraulic mulches, straw mulch, straw-net, and excelsior erosion control blankets with seed and fertilizer to control erosion and establish permanent vegetation on highway rights-of-way. The rates of application have been the maximum that would still allow the establishment of vegetation. Consequently, it has been observed that erosion is better controlled with erosion control blankets or the commercial hydraulic mulches and, as a result, decisions on the erosion control strategy to use have been based on the intuitive judgement of the designer based on his experience. Generally, the height of cut or fill is of more importance in these decisions than are other factors such as soil erodibility or the amount and intensity of rainfall. Overall, seed and mulch have been used on the flatter slopes while the erosion control blankets have been employed on the steeper slopes. Straw and seed with an asphalt tackifier remains the second choice of the industry based primarily on its greater cost and inconvenience over the commercial products.

The results of this approach have not been acceptable either to the Ministry or the regulatory bodies; the more erodible slopes have frequently failed even under low intensity, high frequency storms of as small as a two year storm. These failures have frequently caused severe impacts to sensitive watercourses, woodlots, private properties and have resulted in increased construction costs.

The problem has two facets. The first is the unavailability to Ministry designers of a model that can bring together all the factors controlling erosion into an index of erosion susceptibility for a given site. With such information, a designer can calculate the erosion susceptibility of a slope and specify in the contract those products equal in erosion control capability so that during the tendering process, the contractor can select the product to use on the basis of product availability, cost, installation difficulty etc.

The second facet is the unavailability of an index of the erosion control capability of each of the erosion control products on the market. This index would express the maximum ability of the erosion control product to control erosion under combinations of slope, rainfall and soil type as determined by test results. The availability of this information would enable a designer to specify in the contrast the use of those products which control the erosion on his slopes as determined by his calculation of the erosion susceptibility index.

The objective of this research was to explore these two facets in greater detail.

2/ Basis of the Approach

Whenever bare soil is exposed to the influences of rain, erosion will occur unless some action is taken to reduce the potential. The Universal Soil Loss Equation (USLE) has been found to be a useful approach to predicting and managing rainfall induced soil erosion (Wischmeier and Smith, 1978).

The USLE is described by the relationship A = R K LS VM where A is the annual rate of soil erosion that can be expected for specified values of the principal factors affecting erosion on slopes. R is the rainfall/runoff factor; K is the soil erodibility factor; and LS is a combined factor expressing the effects of slope length and slope gradient. The derivation of the USLE and its limitations have been described by Wischmeier and Smith, 1968.

VM, also called the soil loss ratio, (SLR) expresses the effect of any vegetative-mechanical treatment applied on a slope and is specific for a particular application such as a specific rate of application of a mulch with a specific concentration of a tackifier. Since it is the ratio of the amount of soil lost from a treated slope against that lost from an identical untreated slope, this constant can be thought of as an index of the effectiveness of an erosion control treatment applied on a slope and its value will be inverse to the effectiveness of the erosion control material.

Graphically, the value of VM is given by the slope of the plot of RKLS(tr) on RKLS(bs) (Figure 1). Theoretically, this relationship should take on either an ascending straight or curvilinear shape. In the former case, (Line A, in Figure 1) the point at which a datum significantly deviates from the trend line represents the breakdown of the erosion control material under test, and further, represents the maximum rate of erosion that can be controlled with that particular material. In the case of a measure exhibiting a curvilinear relationship, (Line B in Figure 1) the increasing value of the slope indicates that the measure is progressively becoming less effective in controlling erosion. While the trend line is below the 45 degree level, where VM = 1.00, the rate of erosion is less than that which would occur if the erosion control measure had not been present. If however, the trend line goes

above the 45 degree level, the rate of erosion is actually greater than would have occurred if no erosion control material had been used.

The capability of an erosion control product to effectively control erosion on a slope is represented by the maximum value of RKLS(bs) (Point X in Figure 1) where the effectiveness of the erosion control material begins to decrease as evidenced by an increase in the value of VM. In the case of those products which demonstrate a curvilinear increase in VM, some standard will be needed against which all products can be referred.

The susceptibility of a slope to erosion can be determined by the product of R, K, and LS values for the slope and assigning a value of one to VM.

Theoretically, the erosion control material that will effectively control erosion on the slope is that which has a erosion control capability equal to or greater than the erosion susceptibility for the slope.

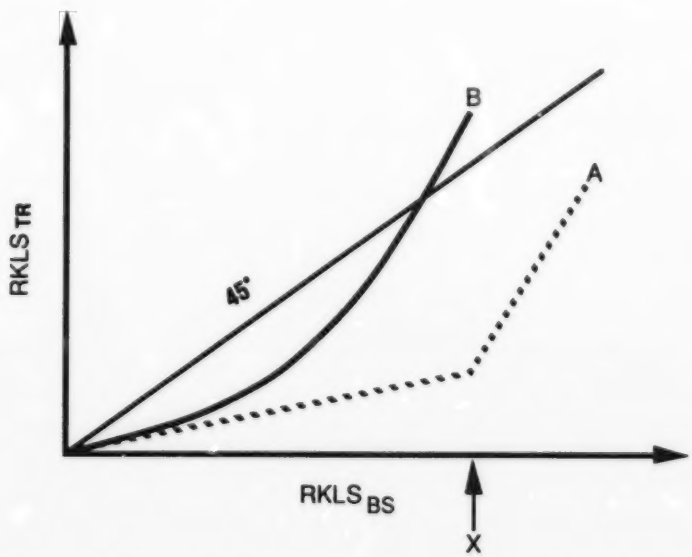


Figure 1/ Theoretical relationships between soil loss from erosion on treated ($RKLS_{TR}$) against untreated ($RKLS_{BS}$) slopes

3/ Testing Methodology

Researchers at the University of Guelph have developed and calibrated a rainfall simulator (GRS-2) for use in field studies of soil erosion and sedimentation. This simulator can produce rainfall intensities ranging from 17.5 mm/h to in excess of 200 mm/h using several low to medium flow-rate jet nozzles in a continuous spray design. The properties of the simulated rainfall have been compared to natural rainfall events in terms of drop size, velocity, and energy (Tossell et al, 1987 and 1990).

3.1/ Study location

A site on an active Ministry construction site was chosen to evaluate an erosion control blanket and a hydraulic mulch on a 2:1 slope. These erosion control materials were applied to MTO specifications adjacent to each other on the slope by the contractor. Control plots (bare soil) were created in the area sprayed with the mulch by placing plywood sheets ($1.5m^2$) on the 2:1 slope before mulch application.

3.2/ On-site procedure

Runoff and erosion plots were established adjacent to each other on the 2:1 slope where the erosion control products had been applied. The plots were established on bare soils and soils where the hydraulic mulch and erosion control blanket had been installed. Each plot consisted of a three-sided metal boundary with the open side in the downslope position. A metal lip and trough was installed at the open end to stabilize the soil at the lower boundary and collect runoff (Wall et al., 1990).

Simulated rainfall was applied to each plot at an intensity of 2.67 mm/min for a duration of 30 minutes (Tossell et al, 1987). Runoff volumes were recorded and sampled at 2 minute intervals for the duration of the experiment. Approximately 100 ml subsamples of runoff were obtained in duplicate for laboratory determination of sediment content.

Surface soil samples (0-20 cm) were collected from sites adjacent to runoff plots for laboratory soil characterization. Immediately prior to runoff experiments, surface soil samples (0-5 cm) were collected in duplicate to measure antecedent soil moisture.

3.3/ Laboratory Procedures

Soil samples were analyzed for particle size distribution, organic matter content, pH and calcium carbonate content after methods described by McKeague (1978). Soil moisture content was determined gravimetrically.

Sediment concentrations in runoff were determined in duplicate gravimetrically by filtering runoff through pre-weighed 0.45 micrometer filters under vacuum pressures.

SLR (VM) factors were calculated at various intervals during the rainfall simulations for the blanket and mulch treatments after methods described by Wischmeier and Smith (1978), and Clyde (1976).

3.4/ Statistical Analysis

Comparisons of runoff, soil loss and sediment concentrations were made amongst the three treatments. Analysis of variance (ANOVA) was performed, utilizing the SAS procedures (SAS Inst. Inc., 1985) to determine whether or not significant differences ($P = 0.05$) existed between the various treatments and replicates. Duncan's Multiple Range Test was used to identify the treatments which differed significantly.

4/ Results and Discussion

The soil characteristics at the study location are reported in Table 1. Soil properties do not show significant variation between the erosion control treatments and bare soil plots. The texture of the soil was loam with approximately 25% clay, 47% silt, and 28% sand. Soil organic matter levels averaged 3.1% while soil pH values ranged from 7.0 to 7.5. Soil erodibility (K) values were calculated after methods described by Wischmeier and Smith (1978) and found to be about 0.26. Mean K values for loam textured soils in Southwestern Ontario of 0.30 have been reported by Wall et al (1984).

The antecedent soil moisture content for the two mulch plots and the two control plots range from 12 to 14%. The following day, after a light rainfall, the antecedent soil moisture content for the two blanket plots and one control plot ranged from 18 to 22%.

Figure 2 shows the rainfall amounts that each plot received over the 30 minute treatment. Rainfall duration/intensity data from the Atmospheric Environment Service was used to calculate the probable return period of rainfall at several times during the runoff study. For example, the rainfall amounts occurring after 4, 6, and 10 minutes of simulation are equivalent to a 5, 10, and 25 year return period storm.

In addition, the rainfall energy factor (EI) of Weischmeier and Smith (1978) for the rainfall event is indicated in Figure 2. For southern Ontario, the average EI value is about 1300 MJ mm/Ha h. This value is reached after approximately 18-20 minutes of rainfall simulation.

Photographs of the runoff plots before and after rainfall simulation are shown in appendix A. For the control plots the effect of the rainfall and runoff energies of breaking down soil aggregates can be seen. While the erosion control blanket is not affected by the rainfall, the amount of mulch that is degraded during the rainfall event is apparent in the photos.

Table 1: Soil characterization of the MTO study site

Plot	Depth	Texture	Gravel	Sand					Sand (total)	Silt	Clay	pH	CaCO3	Organic Material	"K" Value
				Very Coarse	*Coarse*	*Medium*	*Fine*	*Very Fine*							
	(cm)		——	——	——	% by weight	——	——	——	——	——		%	%	
Control 1	0	Loam	3	1.8	2.6	5	8	10.5	27.64	47.4	24.8	7	2.1	3.2	0.26
Mulch	0	Loam	2.6	2.5	2.5	4.3	9.1	9.3	27.62	47	25.4	7	1.6	1.5	0.25
Control 3	0	Loam	3.5	2.6	2.8	5	8.1	10.2	28.6	46.8	24.6	7.2	2.5	3	0.26
	0	Loam	2.2	2.6	2.3	4.2	8.3	9.6	26.9	46.3	26.8	7.5	1.8	3	0.25

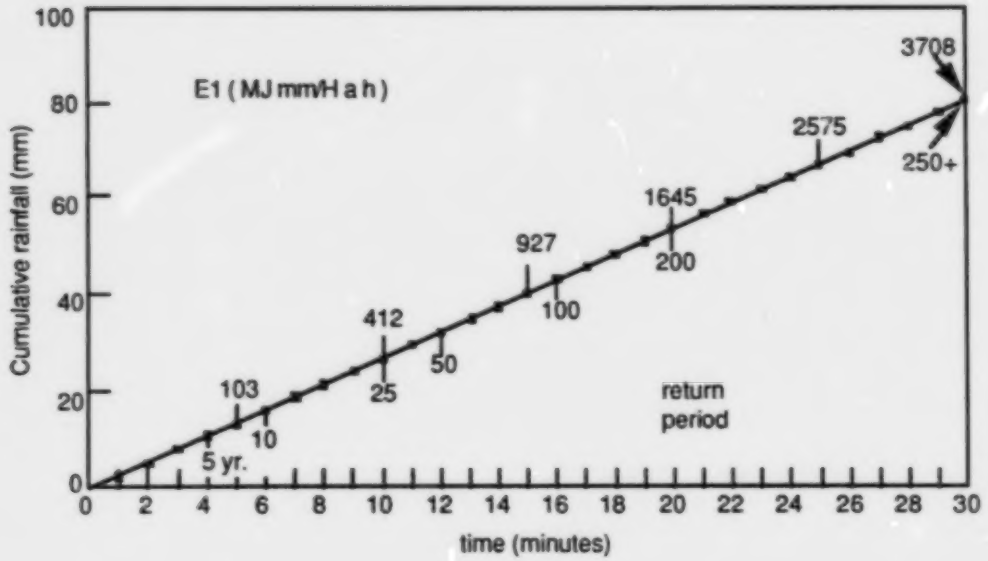


Figure 2/ Cumulative rainfall amount with time and associated E1 values and return-period figures for simulated rainfall

4.1/ Runoff

Average runoff volumes for the three treatments (control, mulch, blanket) are shown in Table 2 and plotted in Figure 3. In the first 6 minutes of the rainfall event, runoff volumes from the control plots are greater but similar to runoff volumes from the plots with the erosion control products. After approximately 10 minutes, runoff from the control and blanket plots are similar and greater than from the mulch plots. After 10 minutes the mulch treatment results is about a 35% reduction in runoff relative to the control plot (Table 2). By the end of the rainfall event the reduction in runoff drops to less than 10%.

Statistical analysis of the data for return period storms ranging from 5 to 200 years are shown in Table 3. For all the return period storms reported, runoff from the control plots are not significantly different ($P = 0.05$) from the runoff from the erosion blanket plots. Runoff from the control and erosion blanket plots are similar for the 5 and 10 year return periods. However, for all the return period storms greater than 25 years, runoff from the mulch plots are significantly lower than for the control plots.

A soil loss ratio (VM or C factor) can be computed for any period up to 30 minutes. Table 4 shows soil loss ratios for the erosion control products for seven selected return period storms. Soil loss ratios for the erosion blanket range from approximately 0.009 to 0.015 with maximum values associated with the 5 to 10 year return period storms.

Soil loss ratios for the mulch range from about 0.05 to 0.12. The soil loss ratios are lowest for the 5 year return period storm and increase progressively through to the 200+ return period storm. The increase in the soil loss ratio with time is reflecting the gradual degradation of the mulch by rainfall and runoff energies.

Table 2: Runoff from control, blanket and mulch plots MTO erosion study

Time (min)	Control Sites		Blanket Sites		Mulch Sites		%
	Interval (mL, average)	Cumulative	Interval (mL, average)	Cumulative	Interval (mL, average)	Cumulative	Reduction from control
0	0	0	0	0	0	0	-
2	600	600	315	315	0	0	100
4	2450	3050	1725	2040	1740	1740	29
6	3327	6377	2865	4905	1915	3655	42
8	3867	10243	3715	8620	2365	6020	39
10	4169	14413	4105	12725	2705	8725	35
12	4113	18526	4395	17120	3195	11920	22
14	4223	22749	4525	21645	3585	15505	15
16	4260	27009	4610	26255	3800	19305	11
18	4560	31569	4745	31000	3910	23215	14
20	4460	36029	4820	35820	3960	27175	11
22	4417	40446	5060	40880	3749	30924	15
24	4500	44946	5095	45975	4045	34969	10
26	4597	49543	5240	51215	3690	38659	20
28	4640	54183	5380	56595	4535	43194	2
30	4643	58826	5475	62070	4255	47449	8

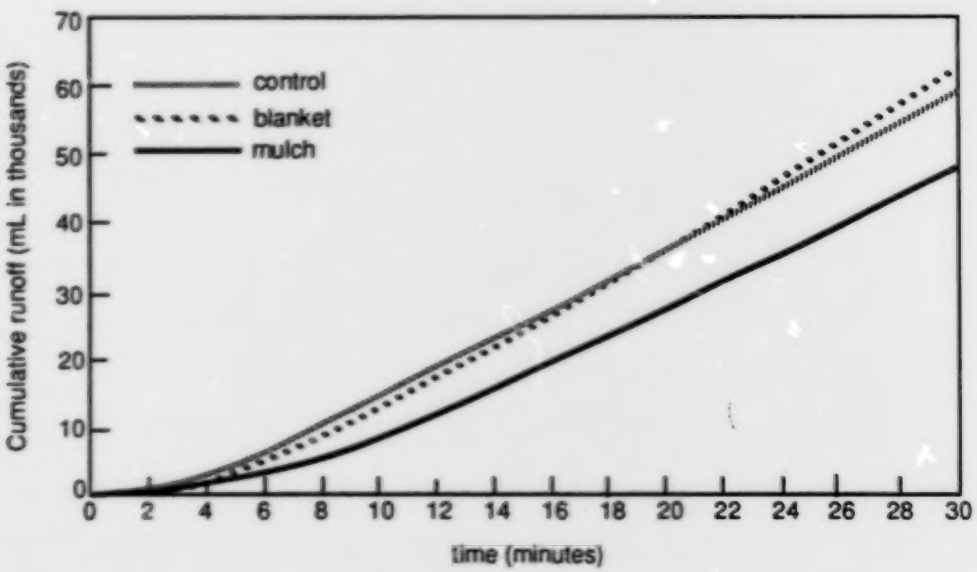


Figure 3/ Runoff from control, blanket and mulch sites (mean values/treatment)

Table 3: Results of ANOVA and Duncan's multiple range tests, MTO erosion study

Return Period (years)	Control Sites	Blanket Sites	Mulch Sites
Runoff			
5	A	A	A
10	A	A	A
25	A	AB	B
50	A	AB	B
100	A	AB	B
200+	A	A	B
250+	A	A	B
Soil Loss			
5	A	B	B
10	A	B	B
25	A	B	B
50	A	B	B
100	A	B	B
200+	A	B	B
250+	A	B	B
Concentration			
5	A	B	B
10	A	B	B
25	A	B	B
50	A	B	B
100	A	B	B
200+	A	B	B
250+	A	B	B

Treatments with the same letters do not differ significantly (p = 0.05)

Table 4: VM values for blanket and mulch covers

Type of erosion protection	Storm return period (years)	VM value
Control plots (bare soil)		1
Blanket	5	0.015
	10	0.012
	25	0.009
	50	0.009
	100	0.009
	200	0.008
	200+	0.009
Hydraulic mulch (Type "C")	5	0.031
	10	0.028
	25	0.036
	50	0.049
	100	0.07
	200	0.09
	200+	0.118
VM values determined from other studies*		
Mulch - wood fibre slurry	1000 lb/acre	0.05
	1400 lb/acre	0.01 - 0.02
	3500 lb/acre	0.01
Blanket - excelsior blanket with plastic net		0.04 - 0.10
- straw or hay, anchored **		0.12 - 0.20

**from National Cooperative Highway Research program manual, Utah State University, 1976.*
*** Wischmeier and Smith, 1978.*

5/ Summary and Conclusions

An onsite experimental procedure using the GRS-2 rainfall simulator to provide quantitative evaluation of erosion control products used during highway construction was developed and tested. The erosion control products were evaluated in terms of control of runoff and soil loss.

Research plots (metre squared) for the two erosion control products (hydraulic mulch and erosion control blanket) installed on 2:1 slopes to MTO specifications and for bare soil conditions were subjected to simulated rainfall at an intensity of 2.67 mm/min for 30 minutes. Runoff and soil loss amounts were determined at 2 minute intervals for the duration of the rainfall event. Effectiveness of the erosion control products was assessed for a range of rainfall intensity-durations equivalent to 2-200+ year return period storms or rainfall energies (EI) of 100-300 MJ mm/Ha.h

The erosion control products differed in their ability to control soil and runoff losses. The erosion control blanket was no different from the bare soil site in controlling runoff. The blanket successfully intercepted the rainfall but appeared to transmit the rainfall downslope without contacting the surface. The hydraulic mulch reduced runoff by approximately 30% relative to the control after 10 to 20 minutes of rainfall but the runoff reduction declined to <10% after 30 minutes.

The erosion control products tested both resulted in significant soil loss reductions relative to the control plots. The blanket resulted in a 98-99% reduction of soil loss for the entire 30 minute rainfall event. The hydraulic mulch had a >95% erosion control reduction for the initial 10 minutes of the event but this reduction was reduced to 85% and 71% after 20 and 30 minutes respectively. The erosion control of the mulch treatment deteriorates as the hydraulic mulch degrades with time. Visual observation of the mulch at the end of the event indicated that approximately 50% of the cover provided by the mulch had deteriorated. Soil loss ratios (SLR) for the blanket (0.01) and hydraulic mulch (0.05 to 0.14) were similar to values reported in the literature.

The proposed methodology was found to be an effective method for quantitatively assessing the effect of control products in reducing rainfall-induced runoff and soil loss. The study procedure is well suited to providing a standard evaluation of a wide range of erosion control products under on-site conditions.

The results indicate that the value of VM (or SLR) is constant over the range of erosion severity and is a measure of the effectiveness of the product having constant specifications in materials and/or application. These findings suggest that the USLE can be used as a measure of the erosion potential of a site when treated with a product having a known effectiveness. The matching of an untreated slope having a known potential erosion susceptibility (from the USLE where VM = 1) with an erosion control material (or product) having an equivalent erosion control capability should minimize erosion induced site cleanup problems, result in improved vegetation establishment and reduce off-site environmental degradation.

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Appendix



Field study location



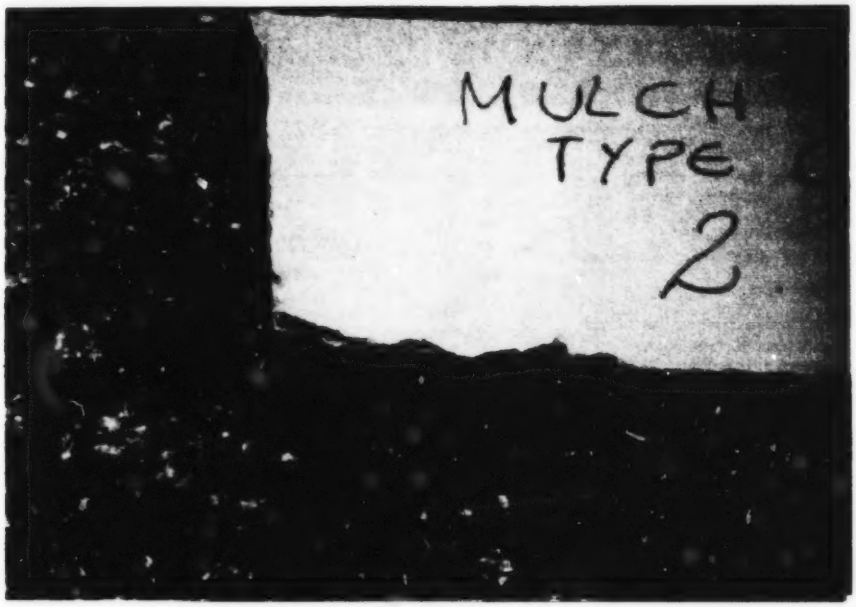
Control plot before rainfall



Control plot after rainfall



Hydraulic mulch before rainfall



Hydraulic mulch after rainfall



Erosion blanket control